Performance of Resistive Plate Chamber operated with new environmental friendly gas mixtures

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Outline

Green House Gas (GHG) Emission from particle detection at LHC

Resistive Plate Chamber gas mixture and possible replacements

Experimental results with eco-friendly gas mixtures

Conclusions
A greenhouse gas is any gaseous compound that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere.

GHG for particle detection at LHC

![Chemical structures](image)

- C$_2$H$_2$F$_4$: GWP 1430
- SF$_6$: GWP 5700
- CF$_4$: GWP 22200

### GHG emission in Run1 [%]

<table>
<thead>
<tr>
<th>Detector</th>
<th>ATLAS</th>
<th>CMS</th>
<th>ALICE</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>C$_2$H$_2$F$_4$</td>
<td>25</td>
<td>40</td>
<td>50</td>
<td>37.5</td>
</tr>
<tr>
<td>SF$_6$</td>
<td>12.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF$_4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Contributions

- RPC
- RICH
- CSC
- MWPC
- GEM
F-gas regulation in Europe

European Union “F-gas regulation”:
- Limiting the total amount of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- Banning the use of F-gases in many new types of equipment where less harmful alternatives are widely available.
- Preventing emissions of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases at the end of the equipment’s life.

HFC phase down
- C$_2$H$_2$F$_4$ is being phased out by EU
- C$_2$H$_2$F$_4$ and SF$_6$ will remain available for research applications
- But price could raise…

**HFC phase down schedule**
* by Linde Group
The RPC gas mixture

At the very beginning
 RPC worked with Ar and/or R13B1

Replacement of
R13B1 with R134a

Nowadays we look for a replacement for R134a

Hydro-Fluoro-Olefin (HFO)

- C=C double bond
- fluorine-containing
- hydrogen-containing

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Refrigerant properties of both HFOs are well known while studies of ionisation processes in particle detectors have started...
Experimental set-up

- Two Resistive Plate Chambers:
  - high pressure laminate
  - 2 mm gas gap
  - read-out strips of 2.1 cm

- Electronics
  - CAEN Digitizer V1730: 16 Channel 14-bit 500 MS/s
  - digitalization of analog signal

- Gas system components validation
  - GC/MS gas analysis
  - Interaction between new gases and gas system components

**RPC operation needs to consider ATLAS-CMS requirements and conditions (i.e. existing HV cables, FEB electronics)**
Validation of gas and detector components

Requirements for the use in LHC experiments

- Not-flammable gas mixture
  - Some of the gas tested are slightly flammable
  - Not possible to use a flammable gas mixture if leaks are present
- Low vapour pressure at ambient temperature
  - Not enough pressure for operation: it represents a limitation to the maximum delivered flow
  - It might lead to vapour condensation in the gas system
- Mass Flow Controllers
  - Found oily-like pollution in HFO sample bottles
  - MFC suffer pollution: protection of input necessary
  - Calibration with new gases not always available
- Quality of new freons is fundamental for detector operation
  - the selected gases have been developed to be used as refrigerants in industries
  - they could not fully satisfy the detector or experiments requirements
- Gas Chromatograph and mass spectrometer analysis
  - detection of impurities in some samples
Analysis steps

- **Streamer**: poor rate capability, high signal
- **Avalanche**: good rate capability, low signal

**Recording of analog signals**

- Parameters extracted from the signal:
  - pulse height
  - integrated charge
  - time
- Detector performance analysis:
  - efficiency
  - pulse height for avalanche and streamer
  - charge for avalanche and streamer
  - avalanche vs streamer probability
  - cluster size
  - time resolution
HFO vs R134a

HFO in RPC standard gas mixture
- Both HFOs substituted to C$_2$H$_2$F$_4$, iC$_4$H$_{10}$ or SF$_6$ to study the properties of the new gas
  - similar behaviour of the two HFOs
  - HFOs are much less electronegative than SF$_6$
  - HFOs has different quenching effects than iC$_4$H$_{10}$
- HFOs cannot directly replace C$_2$H$_2$F$_4$
  - higher applied voltage necessary (>14kV)
  - very small avalanche signal

Addition of Argon
- Argon helps in charge developing
  - Ar becomes the first player
- RPCs work in streamer mode
  - not suitable for LHC operation
  - ok for rate < 10Hz/cm$^2$
Addition of He

- Helium helps in reducing the HV working point
  - in first approximation it doesn’t take part in the avalanche processes
  - it helps to reduce the gas partial pressure
- Addition of He in different percentages
  - 30% - 50%
- Increase of streamer probability
  - due to drastically reduction of the \( \text{C}_2\text{H}_2\text{F}_4 \)
  - slight increase of SF\(_6\) does not help

\[ H V_{\text{eff}} = H V_{\text{appl}} \frac{p_{\text{STD}}}{p} \frac{T}{T_{\text{STD}}} \]
Addition of He and C$_2$H$_2$F$_4$

- Addition of He does not work for LHC conditions
  - C$_2$H$_2$F$_4$ is still the main contributor for charge reduction
- Try with gas mixtures containing both HFO and C$_2$H$_2$F$_4$
  - HFO reduces the GWP
  - C$_2$H$_2$F$_4$ reduce the signal charge
  - gas mixture GWP is lower than standard RPC gas mixture

![Graph showing efficiency and streamer probability vs. high voltage]
Addition of CO₂

- CO₂ is used as quencher gas in gaseous detectors
  - typical gas mixtures are Ar/CO₂ (70/30 or 85/15) and Ar/CO₂/CF₄ (in different proportions)
- CO₂ is less quencher than iC₄H₁₀
  - RPC uses about 5% of iC₄H₁₀
- Addition of HFO and CO₂ to standard gas mixture

All gas mixtures have same quantity of R134a and HFO
Other possible environmental friendly gases

Alternatives to $C_2H_2F_4$ (GWP 1430):

Hydro-Fluoro-Carbon (HFC)

- HFC-245fa ($C_3H_3F_5$), GWP 1030
- HFC-32 (flam) ($CH_2F_2$), GWP 675
- HFC-152a (flam) ($C_2H_4F_2$), GWP 120

Alternatives to $SF_6$ (GWP 22200)*:

- Trifluororiodomethane ($CF_3I$), GWP <5
- HFB ($C_4F_6$), GWP 260
- (toxyc!) ($C_3F_6$), GWP <5

* ... and to $CF_4$ (GWP 5700)

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Example with other HFC (R152a)

- R152a (C\(_2\)H\(_4\)F\(_2\)) vs R134a (C\(_2\)H\(_2\)F\(_4\)): missing two fluorines!
  - equal chemical structure (ethane)
  - R152a GWP: 120
  - R152a: 2/8 \(\rightarrow\) 20%
  - R134a: 4/8 \(\rightarrow\) 50%

- RPC efficient and low streamer probability
  - Region without streamer limited
  - Need to add SF\(_6\)

- R152 is flammable
Example with other HFC (R32)

- \( \text{R32 (CH}_2\text{F}_2 \text{) vs R134a (C}_2\text{H}_2\text{F}_4 \text{): missing one carbon and two fluorines!} \)
  - \( \text{R32 has a very simple chemical structure based on methane} \)
  - \( \text{R32 has one carbon and two fluorine atoms less than R134a making suppose that the} \)
    \( \text{electron attachment is lower} \)
- \( \text{RPC efficient at lower working point} \)
- \( \text{Streamer probability is almost 100%} \)
  - \( \text{Poor quenching capacity} \)

\[\text{GWP} \sim 1000\]
## Summary of results

### More than 50 gas mixtures tested

<table>
<thead>
<tr>
<th>Chem struct</th>
<th>GWPmix</th>
<th>HV (V)</th>
<th>Streamer (%)</th>
<th>Pulse charge (pC)</th>
<th>ΔV Eff-Stream (V)</th>
<th>Clu Size (strip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R32-iC₄H₁₀-SF₆ 0.6</td>
<td>c</td>
<td>1030</td>
<td>7500</td>
<td>14</td>
<td>0.5 / 6.5</td>
<td>600</td>
</tr>
<tr>
<td>R134a-iC₄H₁₀-SF₆ 0.3</td>
<td>c-c</td>
<td>1490</td>
<td>9600</td>
<td>1.5</td>
<td>0.5 / 6</td>
<td>1000</td>
</tr>
<tr>
<td>R152a-iC₄H₁₀-SF₆ 0.6</td>
<td>c-c</td>
<td>430</td>
<td>10000</td>
<td>10</td>
<td>1 / 8.5</td>
<td>760</td>
</tr>
<tr>
<td>R245fa-iC₄H₁₀-SF₆ 0.6-He 50</td>
<td>c-c-c</td>
<td>1260</td>
<td>6600</td>
<td>20</td>
<td>1 / 7</td>
<td>610</td>
</tr>
<tr>
<td>HFO-iC₄H₁₀-SF₆ 0.3-Ar 42.5</td>
<td>c=c-c</td>
<td>130</td>
<td>8900</td>
<td>70</td>
<td>2 / 15</td>
<td>160</td>
</tr>
<tr>
<td>HFO-iC₄H₁₀-SF₆ 0.6-He 50</td>
<td>c=c-c</td>
<td>370</td>
<td>9000</td>
<td>20</td>
<td>1.5 / 8</td>
<td>700</td>
</tr>
<tr>
<td>HFO-R134 37.45-iC₄H₁₀-SF₆ 0.6-He 20</td>
<td>c=c-c</td>
<td>890</td>
<td>10500</td>
<td>1.8</td>
<td>0.5 / 6</td>
<td>970</td>
</tr>
<tr>
<td>HFO-R134a 40-iC₄H₁₀-SF₆ 0.6-He 20</td>
<td>c=c-c</td>
<td>730</td>
<td>10500</td>
<td>8</td>
<td>0.5 / 6.5</td>
<td>700</td>
</tr>
<tr>
<td>HFO-R134a 50-iC₄H₁₀-He 20</td>
<td>c=c-c</td>
<td>430</td>
<td>10800</td>
<td>50</td>
<td>1.5 / 8</td>
<td>400</td>
</tr>
<tr>
<td>HFO-R134a 22.5 -iC₄H₁₀-CO₂ 50- SF₆ 1</td>
<td>c=c-c</td>
<td>560</td>
<td>10500</td>
<td>5</td>
<td>0.5 / 6.5</td>
<td>950</td>
</tr>
</tbody>
</table>

- C and C2 structures —> direct operation
- C3 structure —> addition of Ar, He or CO₂
  - Ar brings to high streamer probability
  - He reduces the HV working point
  - CO₂ based gas mixtures look promising
- Still necessary to have R134a in the mixture to be competitive to standard gas mixture
Conclusions

Several reasons to look for a new RPC gas mixture
- $\text{C}_2\text{H}_2\text{F}_4$ will be subject to phase out and price instability in Europe
- RPC systems at LHC dominate the GHG emission due to particle detection at CERN

Alternatives to $\text{C}_2\text{H}_2\text{F}_4$ already available on the market
- HFO as replacement of $\text{C}_2\text{H}_2\text{F}_4$ as refrigerant
- To be tested for aging, radiation hardness, reactivity to detector and gas components

Not an easy task to find a gas mixture to replace the current one for LHC experiments
- Complex gas mixtures (4-6 components) necessary but still not good as standard one
- Keep going on to search the good gas mixture composition

In case of streamer mode, operation with new environmental friendly gas mixture possible
- Addition of Ar or He reduce the HV working point

For new experiments possible to work with the new environmental friendly gases
- Impact on gas system under control
- Dedicated electronics
- Detector HV working point higher